Experimental study of laser produced gadolinium plasma emitting at 6.7 nm

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Agenda

- Choice of element
- Spectroscopy and Metrology
- Directions for source optimization
- Summary & conclusion

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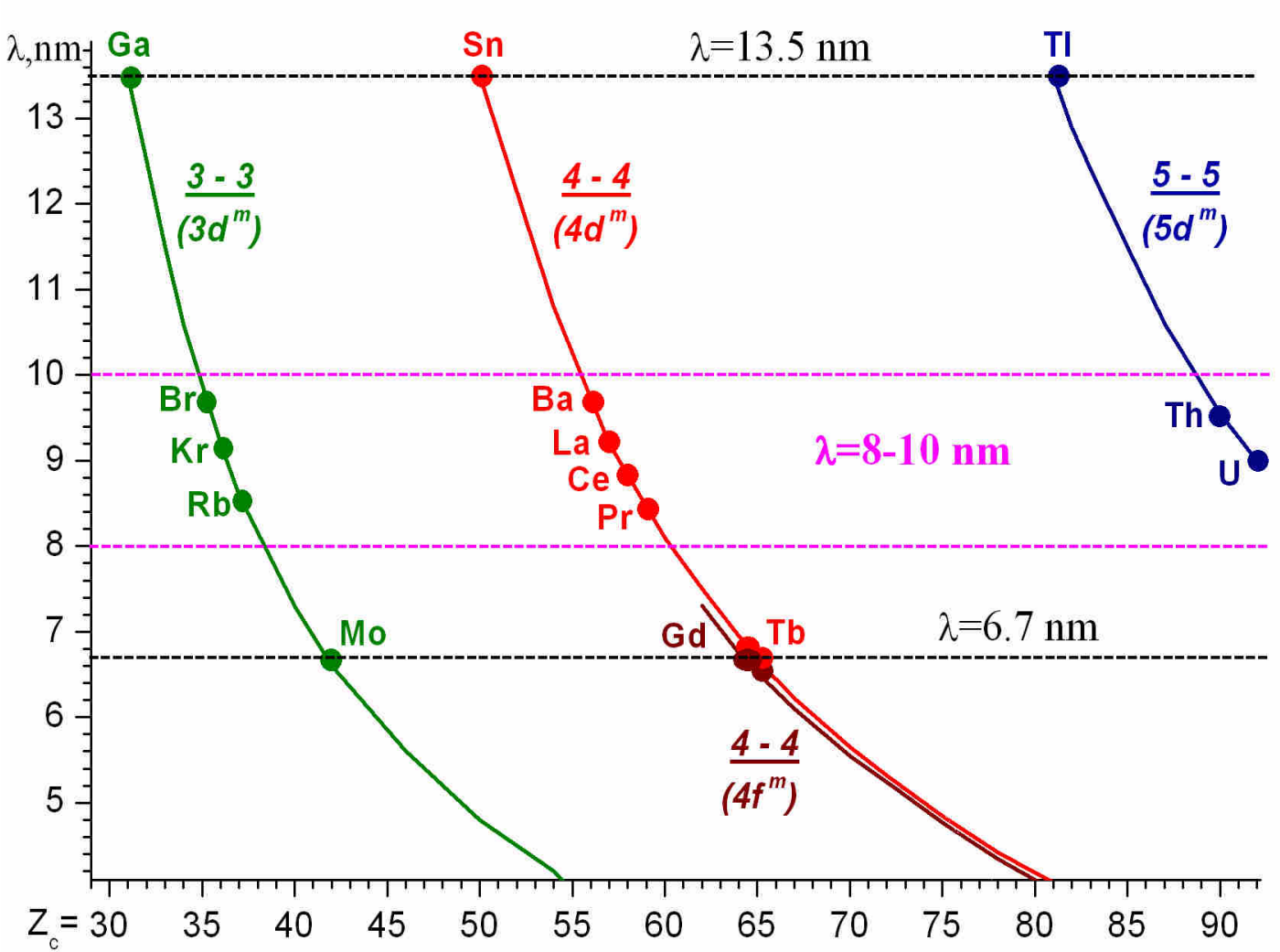
Choice of emitting element

Intense transitions in range of 66.2 – 67.9 Å

Ion (Grnd)	Ionization	T melt	Transition	Intensity (Range)
Na VIII ($2s^2$)	210-265 эВ	98^0C	$2p^2 - 2p4d$	low (66,2-66,7 Å)
Ga XII ($3d^2$)	321 эВ	30^0C	$3d^2$ - 3d4f	high (64,5-66,5 Å)
In XVII-XIX($4p^m$)	430-460 эВ	156^0C	(4p-5s) + (4d-5f)	low (65,5-66,5 Å)
Bi XVII-XIX($5p^m$)	400-460 эВ	271^0C	$4f^{14}5p^m$-$4f^{13}5p^m5d$	medium(64,5-66,5 Å)
As XI ($3d^5$)	292 эВ		$3d^5 - 3d^4$4f	high (65,0-67,0 Å)
Gd XVII ($4f^2$)	372 эВ	1350^0C	$4f^2 - (4f5g+4d^94f^3)$	very high (65,0-67,5 Å)
Tb XXI-XXIX($4d^m$)	650-950 эВ	1356^0C	$4p^64d^m$-$4p^54d^{m+1}$	very high(64.0-69.0 Å)

Transitions in different iso-electronic ions



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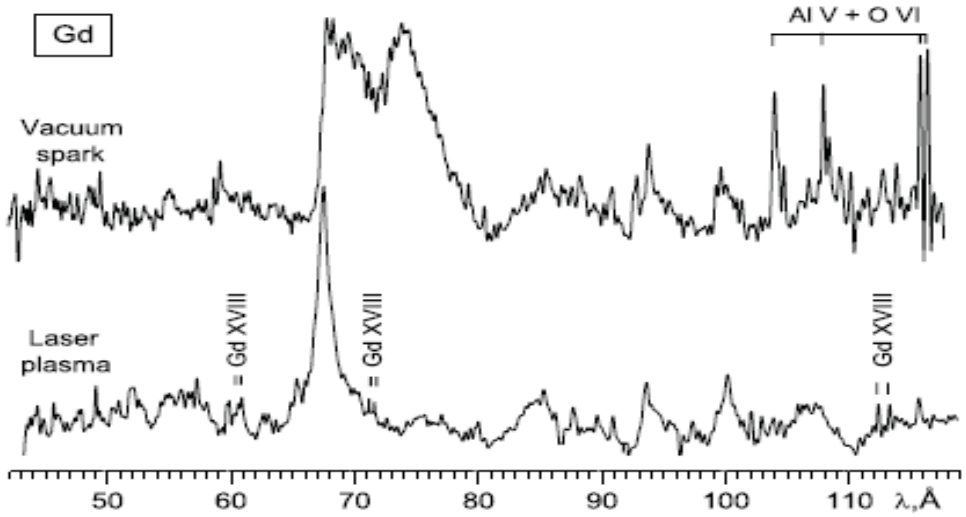
Spectra of Tb and Gd

Experimental

Vacuum spark:
12J, 15 kA, 2μs

Nd Laser:
3J, 20ns, 8e11W/cm^2

2 m GI spectrograph
resolution 0.07 A
accuracy 0.015A



l. Spectra of gadolinium ions excited in the vacuum spark (upper trace) and in the laser-produced plasma (bottom trace).

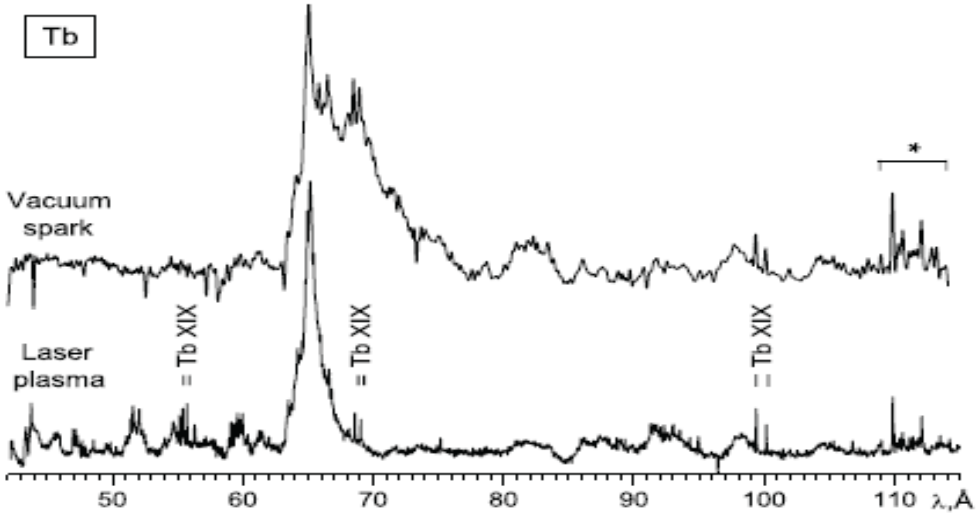
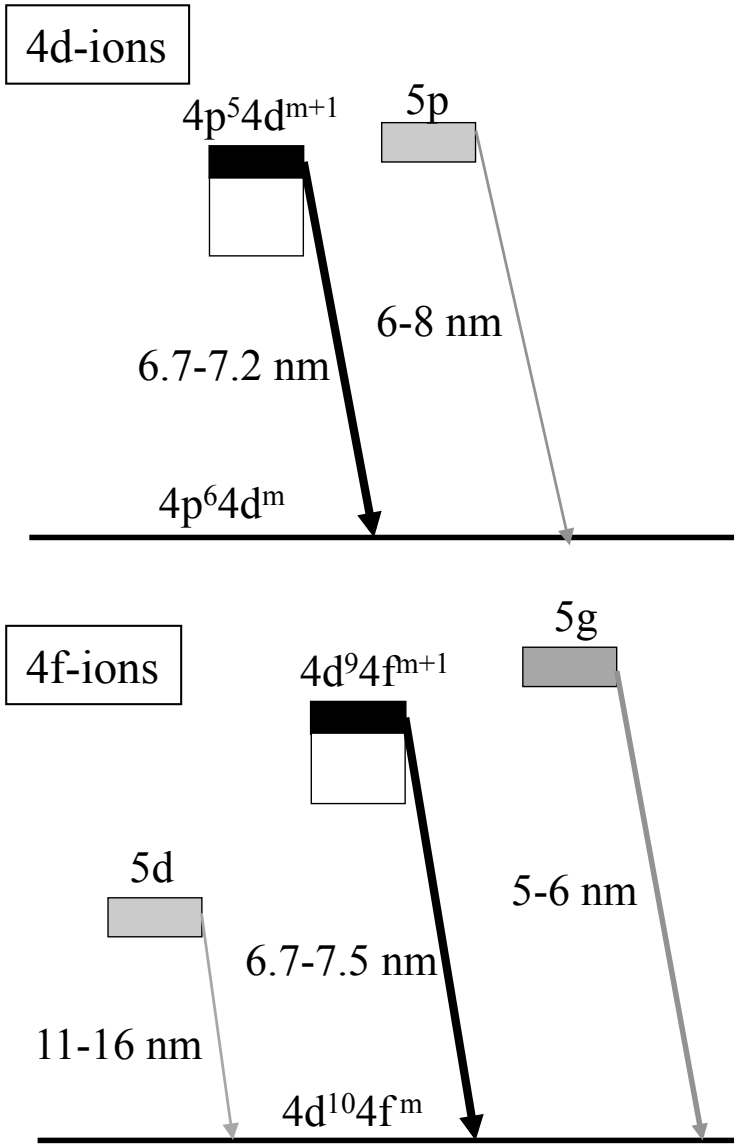
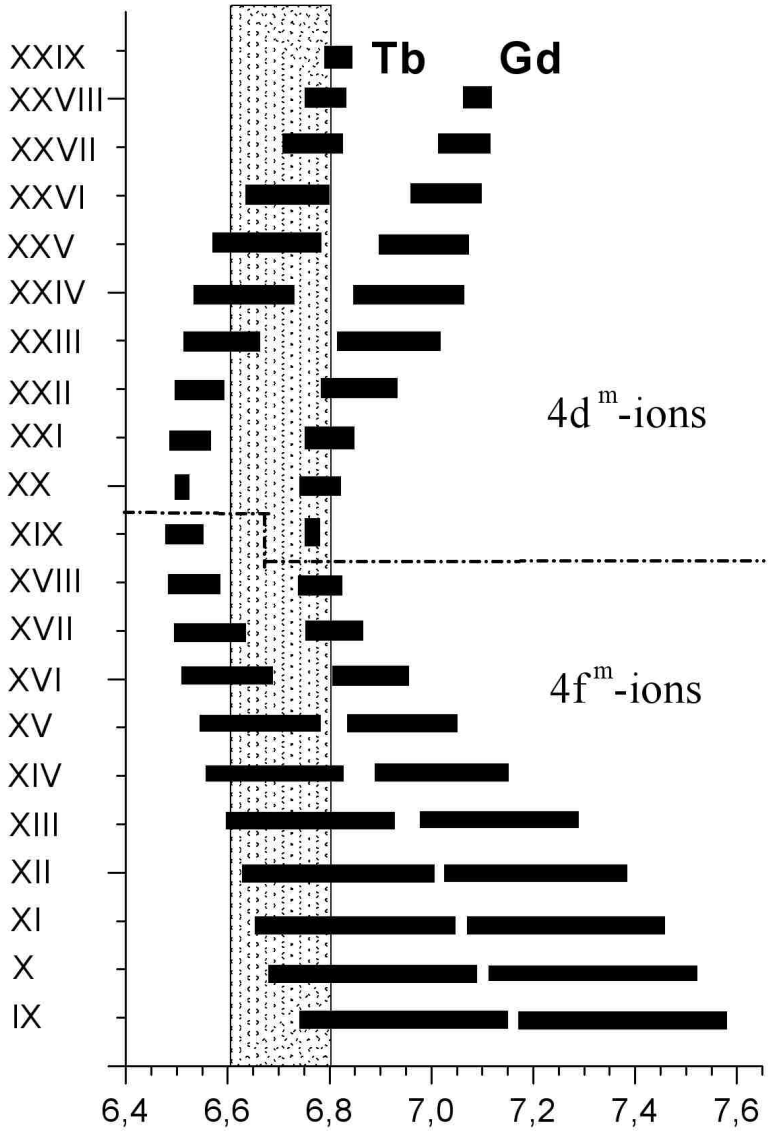


Figure 2. Spectra of terbium ions excited in the vacuum spark (upper trace) and in the laser-produced plasma (bottom trace). *, $4f^2$–$4f5d$ transition array in Tb XVIII classified in the present work.

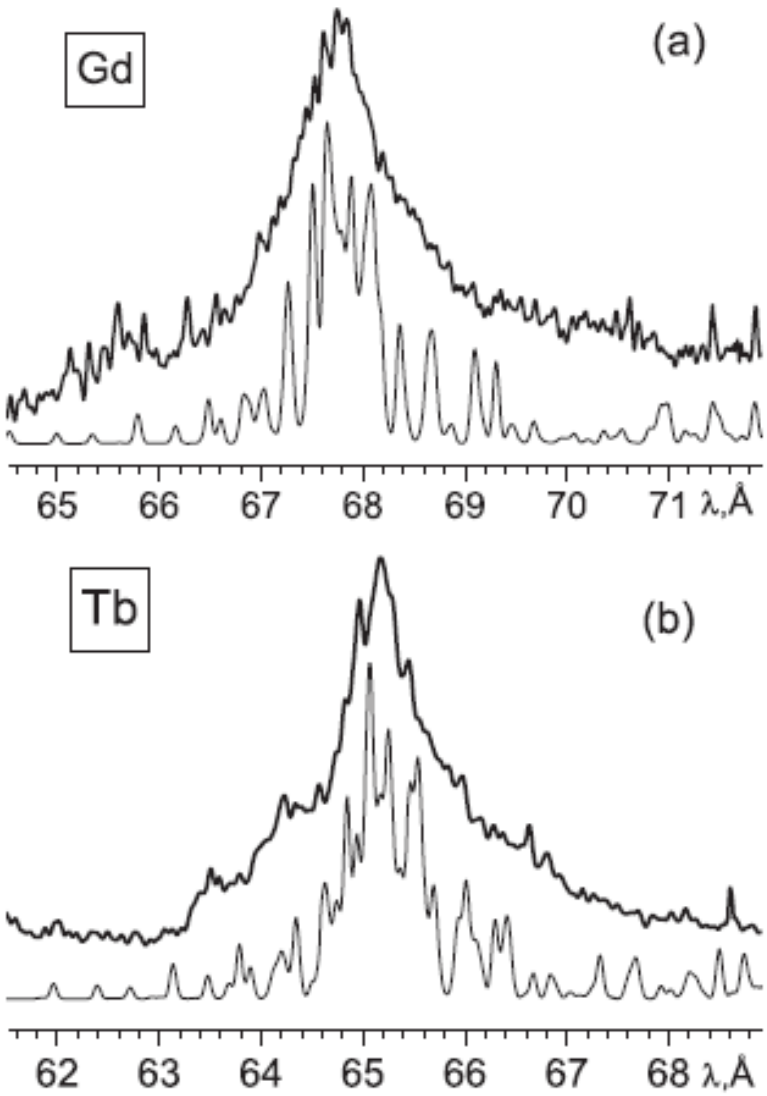
S S Churilov, R R Kildiyarova, A N Ryabtsev and S V Sadovsky Phys. Scr. 80 (2009) 045303

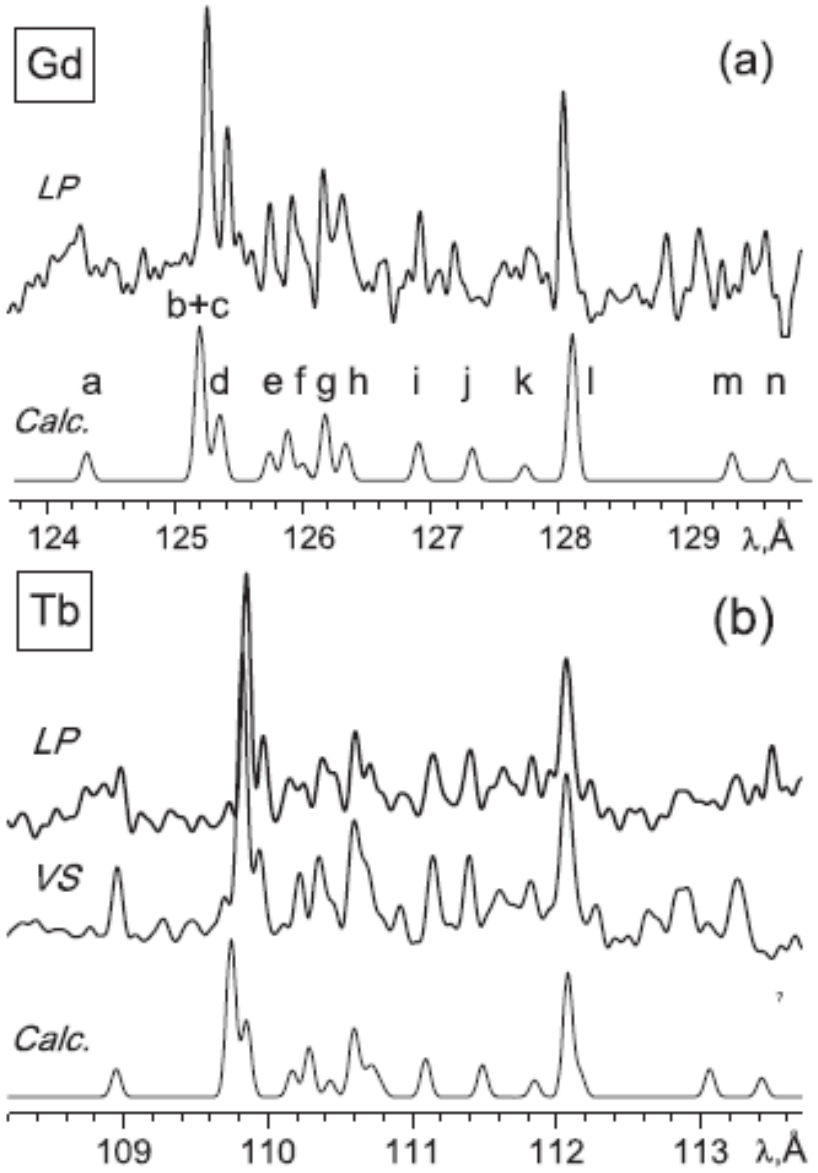
4-4 transitions in Tb and Gd



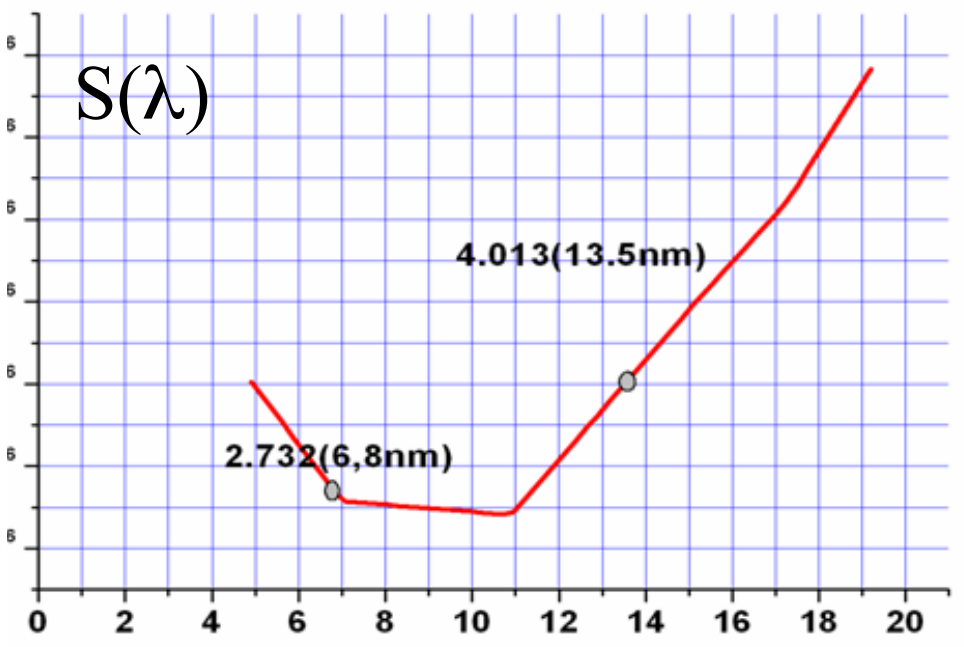


Simulated spectra of Gd and Tb





Energy pre-calibrated spectrometer



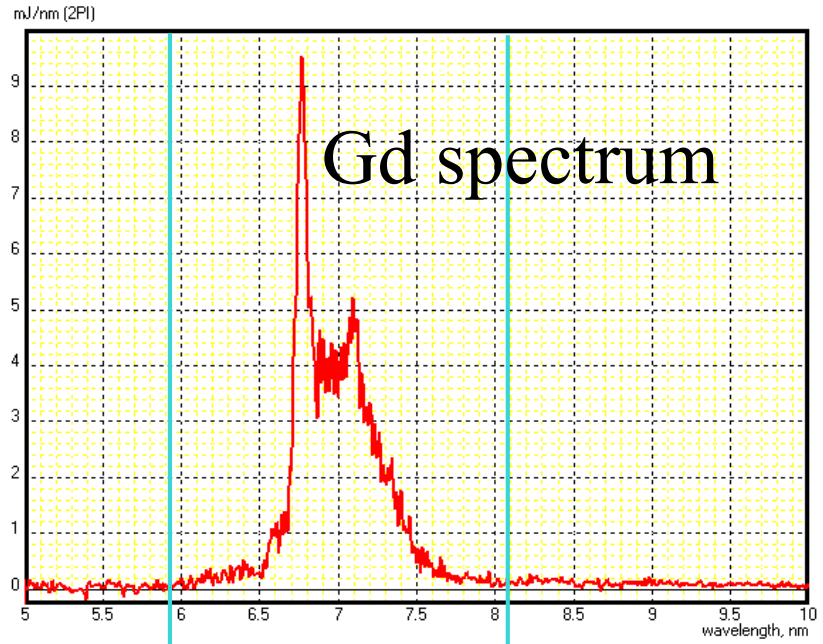
$$I(\Delta\lambda) = \Gamma_{\Omega} \cdot \sum_{\Delta\lambda} N_{\lambda} S(\lambda)$$

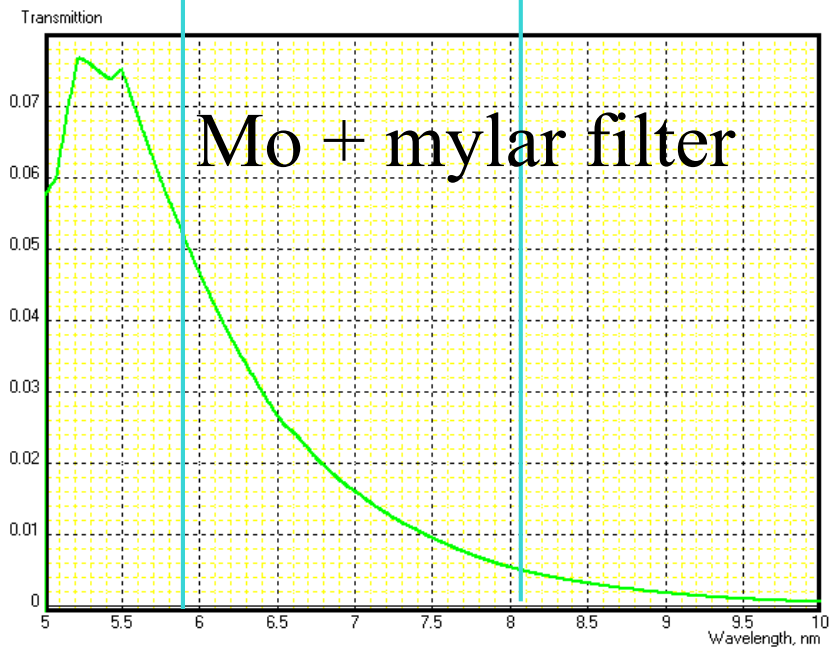
Description:

- **Off-Rowland scheme**
- **Grazing incidence angle 3.0°**
- **Gratings: 1200, 600, 300 mm-1**
- **Spectral range: λ=30 – 400 Å**
- **Spectral resolution: λ/δλ =250-500**
- **Detector: CCD with rear-earth phosphor.**

$I(\Delta\lambda)$ – Intensity [J/str] of the source in the range $\Delta\lambda$
Γ_{Ω} – Geometrical factor
N_{λ} – Signal counts of pixels in $\Delta\lambda$ interval
$S(\lambda)$ – Energy response function of the spectrometer

Spectrometer calibration procedure





$$I(\Delta\lambda) = \Gamma_{\Omega} \cdot \sum_{\Delta\lambda} N_{\lambda} S(\lambda)$$

For narrow banded spectrum S(λ) can be considered as constant, so it can be defined more exact by comparison of measured spectrum with response of calibrated photodiode.

$$\overline{S} = Q_{PD} \Big/ (\Gamma \cdot \Omega \cdot A_{\lambda} \cdot \sum N(\lambda) \cdot F(\lambda))$$

where:

Q_{PD} – Response of photodiode

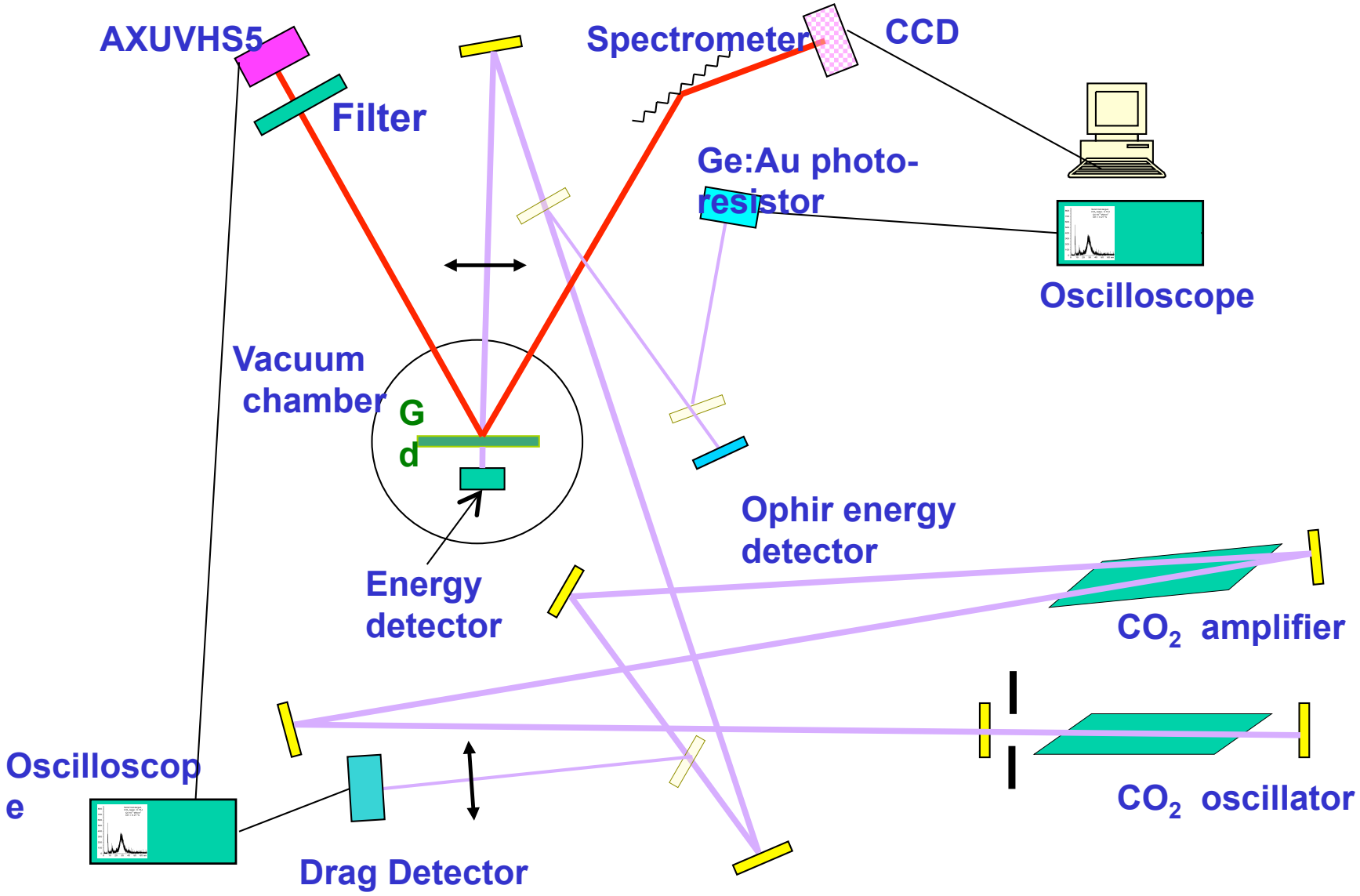
Ω – acceptance solid angle of PD

A_{λ} – photodiode sensitivity (C/J)

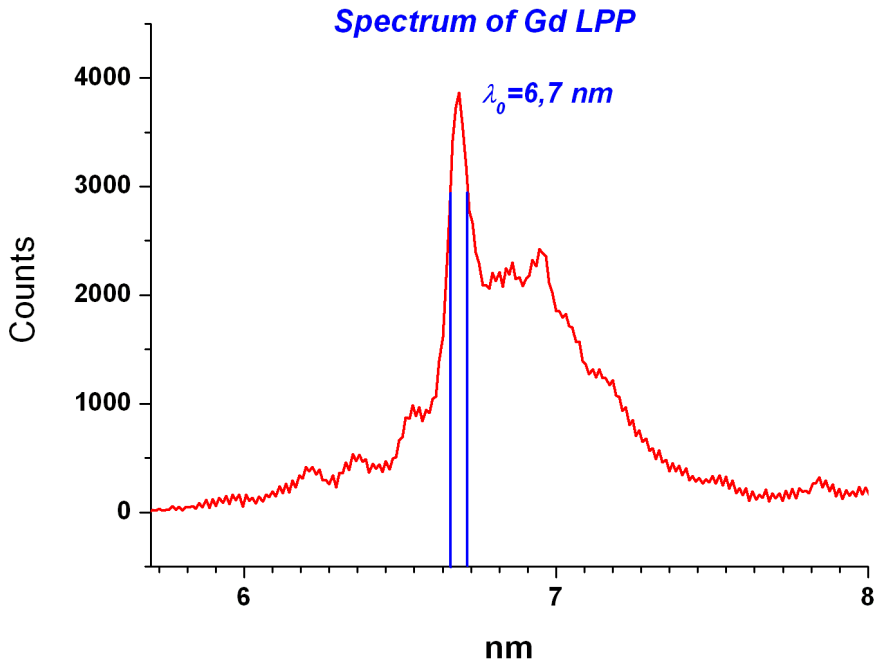
F(λ) – filter transmittion

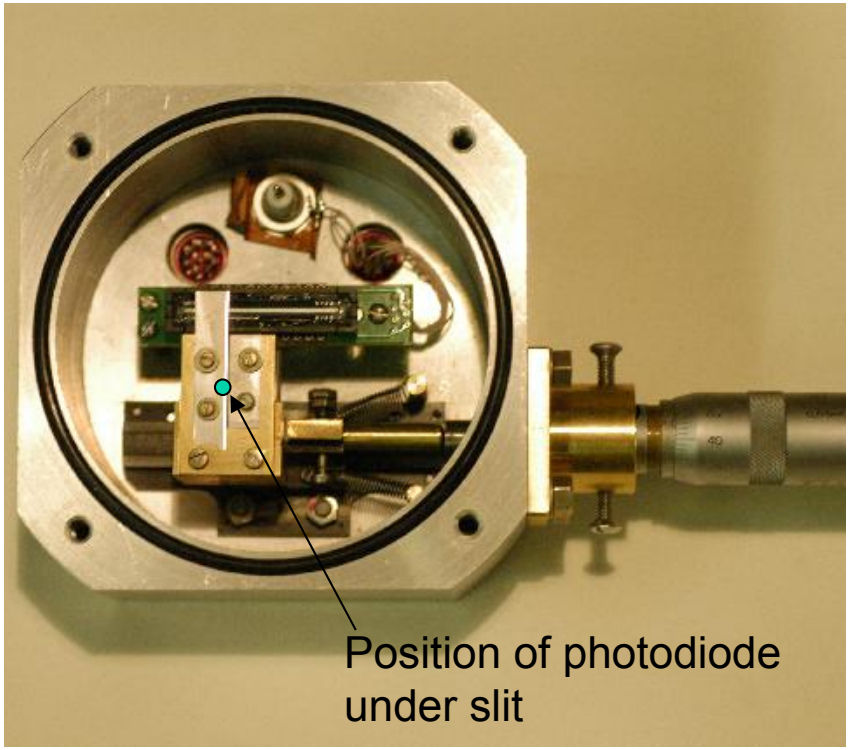
N(λ) - counts of spectrometer CCD

Experimental setup



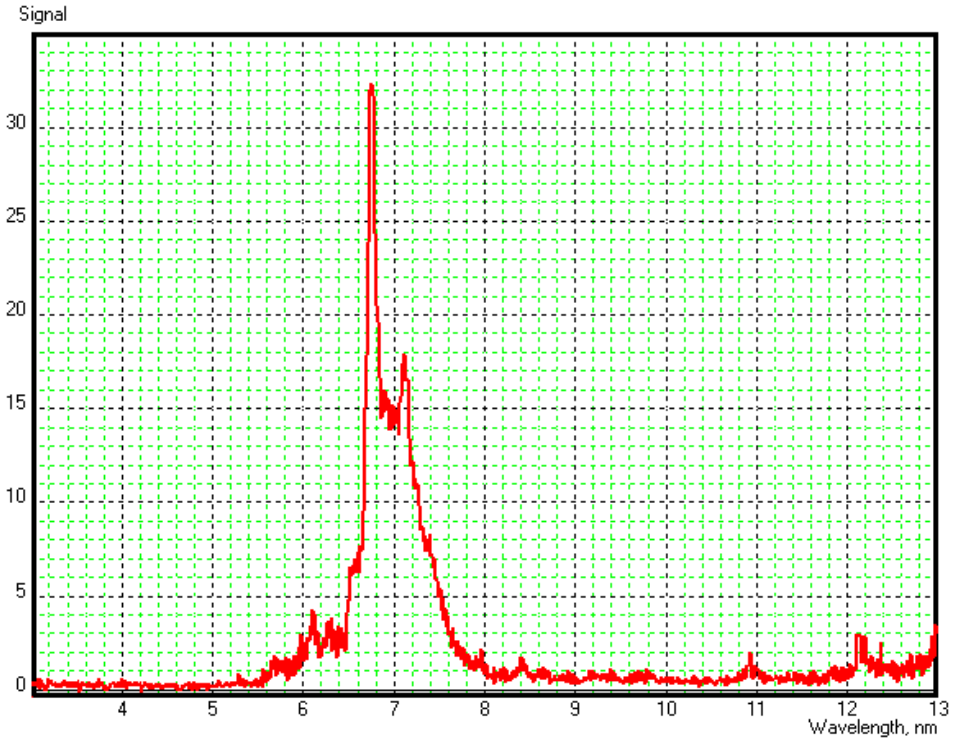
Slit accessory for time-resolved spectrum ranging



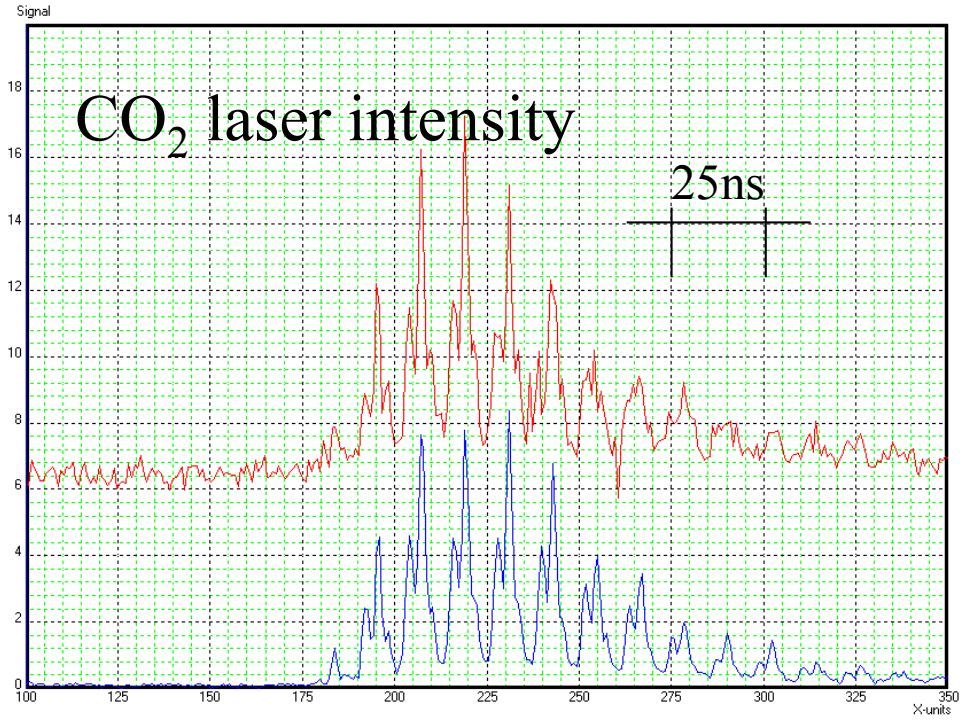


Photodiode AXUVHS5 with 50u slit in spectrometer detector compartment used for time resolved measurements of in-band EUV signal.

View of measured responses



Spectrum of Gd plasma produced with TE CO2 laser



EUV response

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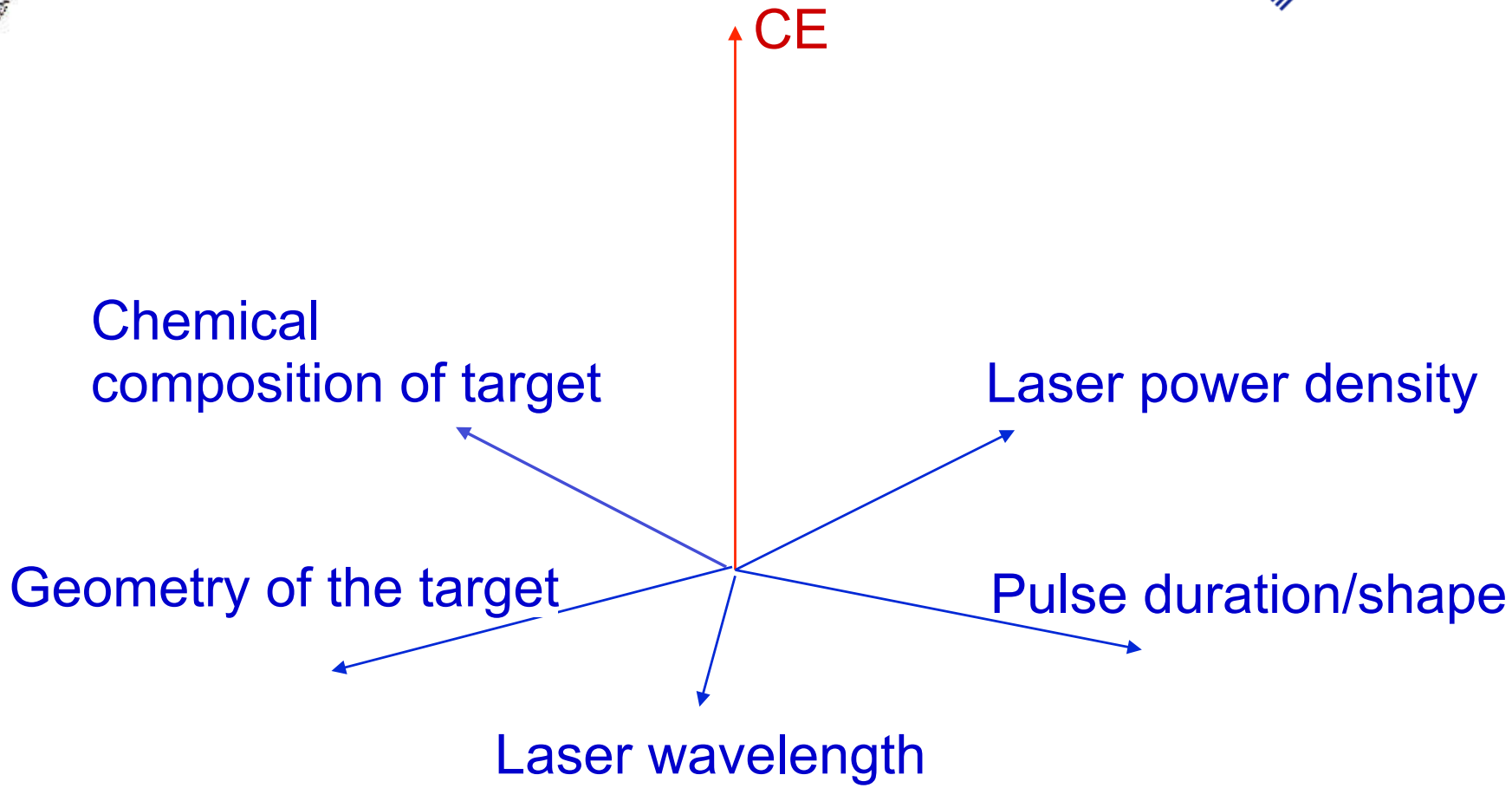
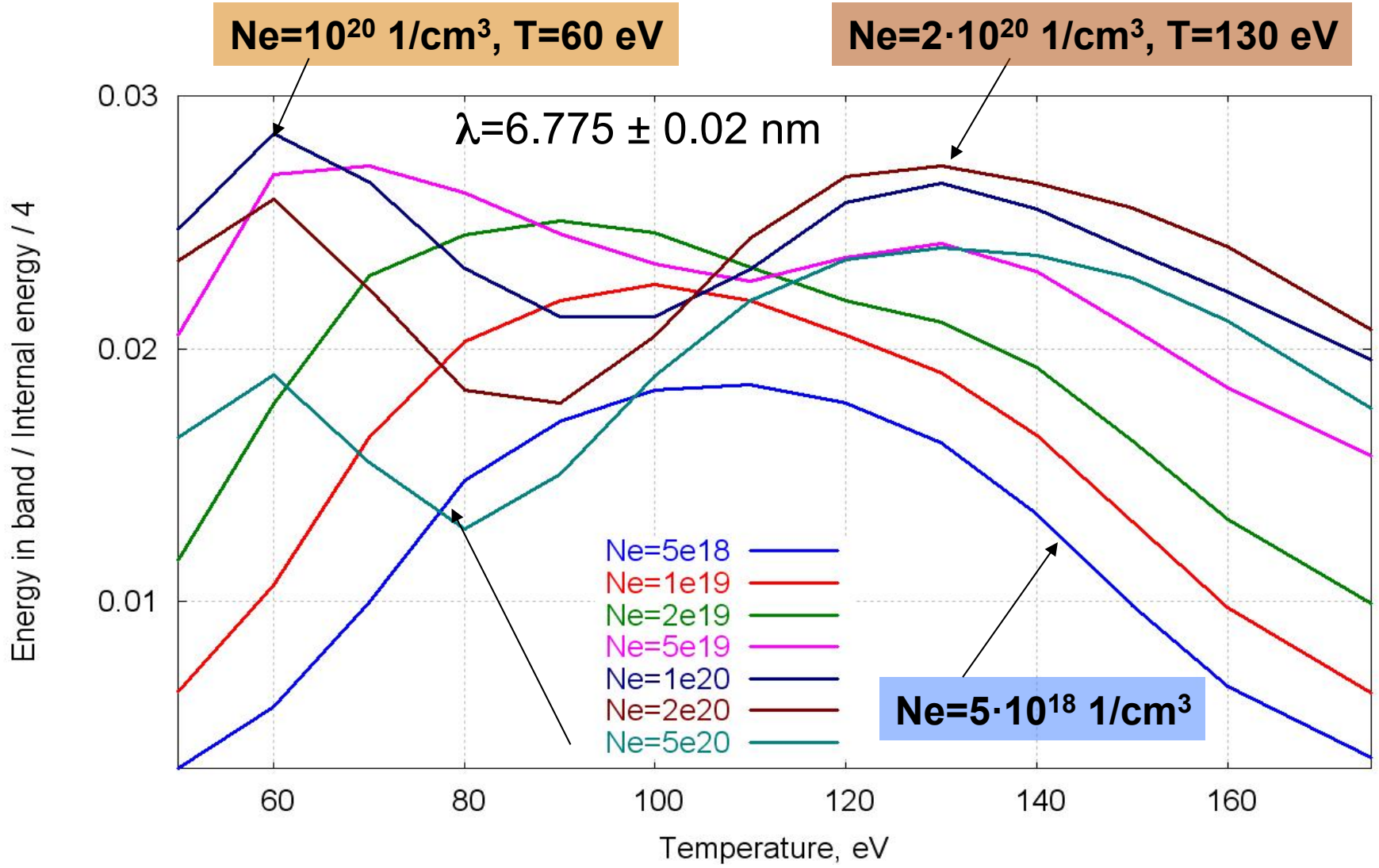
- **Directions for source optimization**
  - laser wavelength
  - Power density
  - Pulse duration
  - Taget geomery
  - Chemical composition of target
- Summary & conclusion



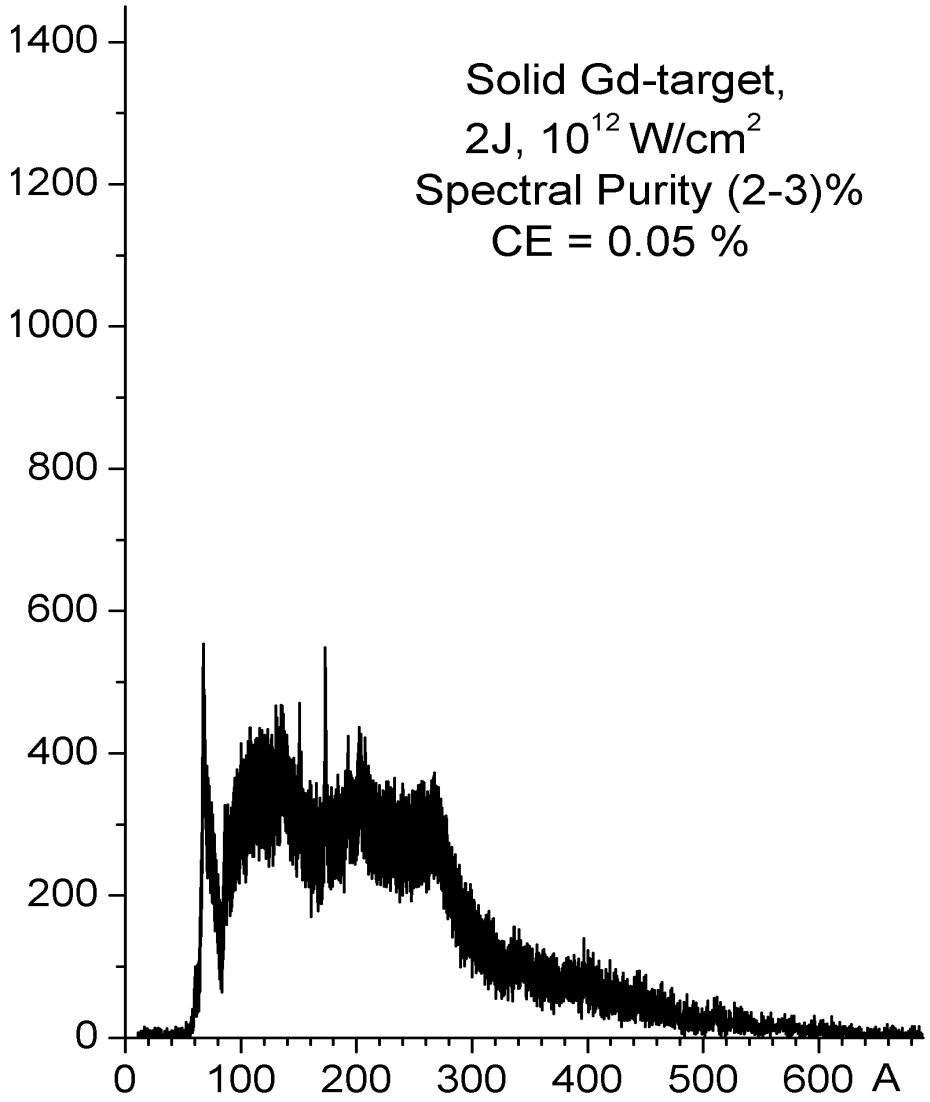
CE optimization is a multi-parameter task

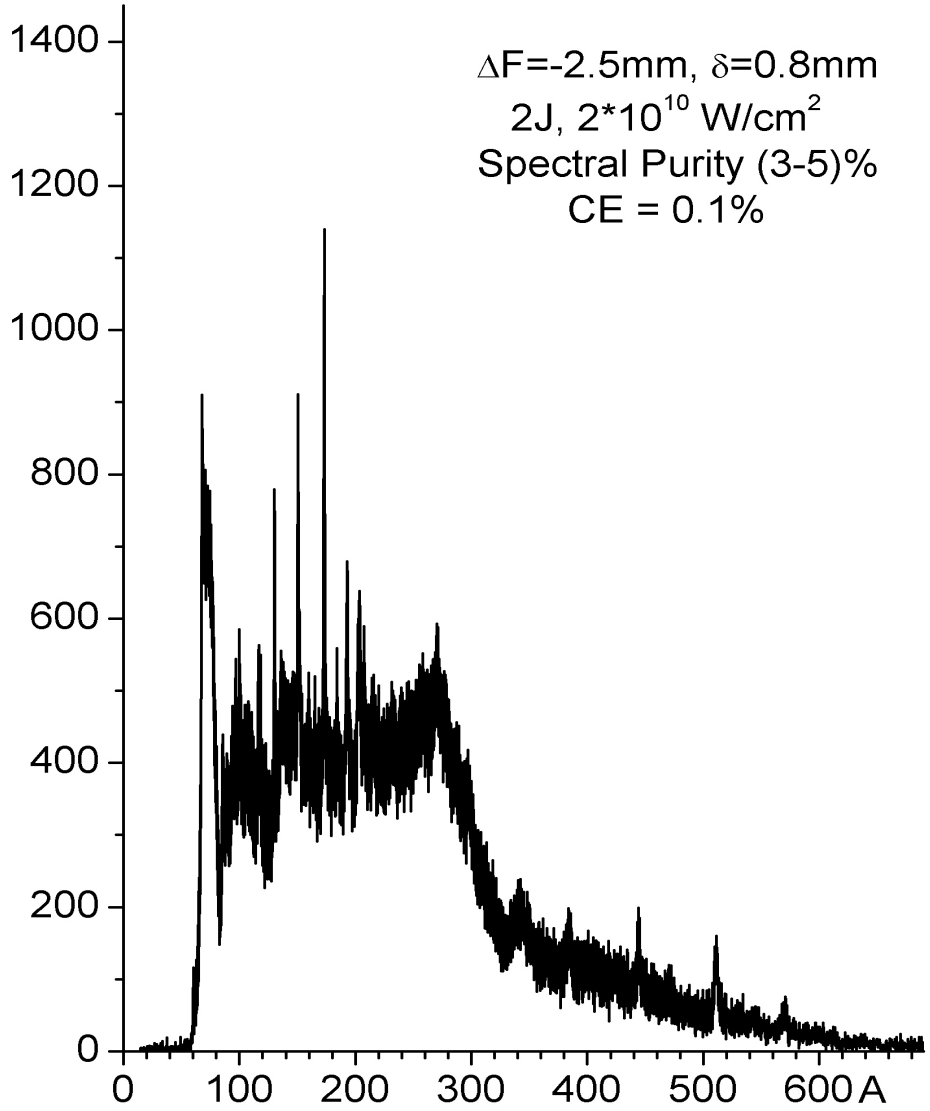
Optimal conditions for Gd plasma

Gd homogeneous droplet R=0.01 cm



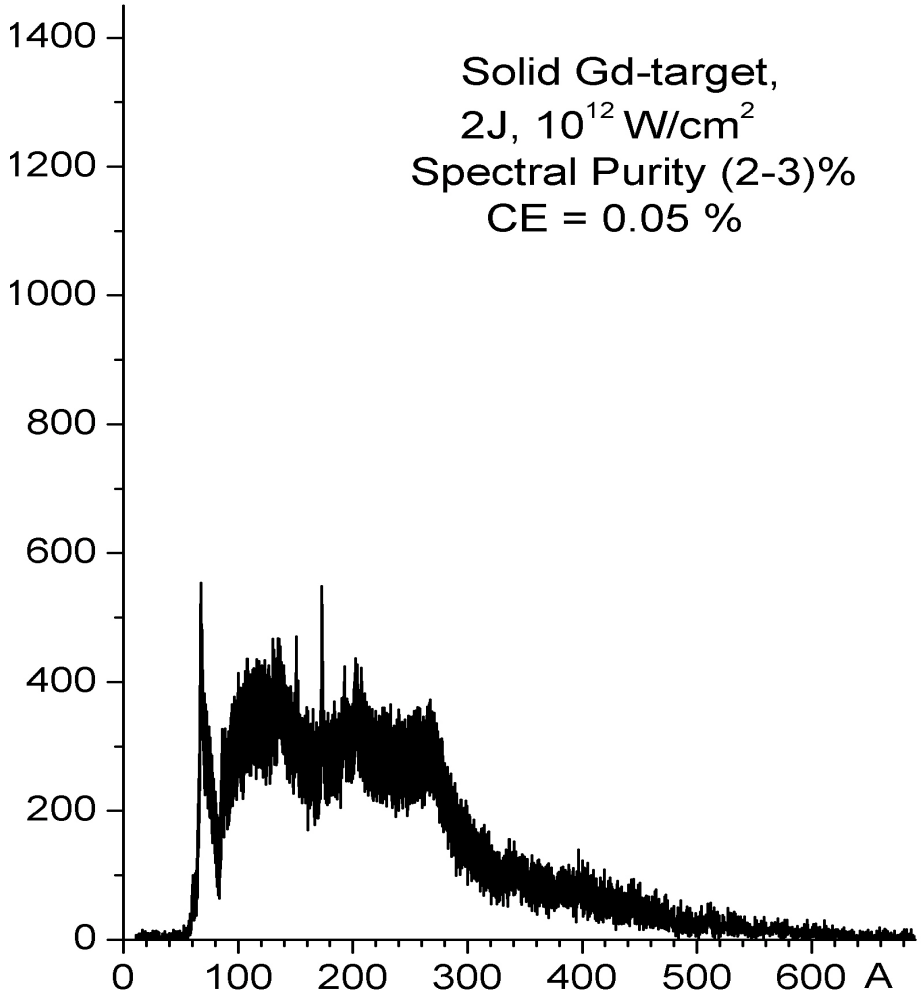
Power density and spot size

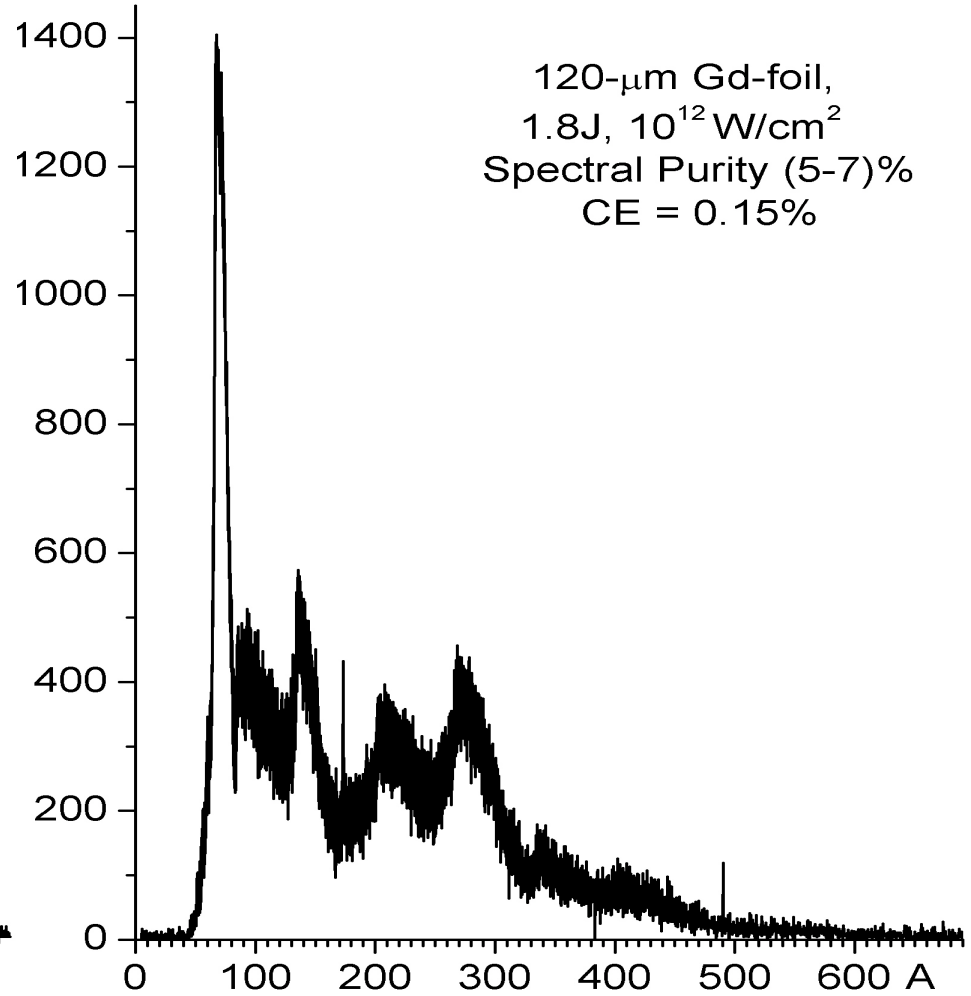




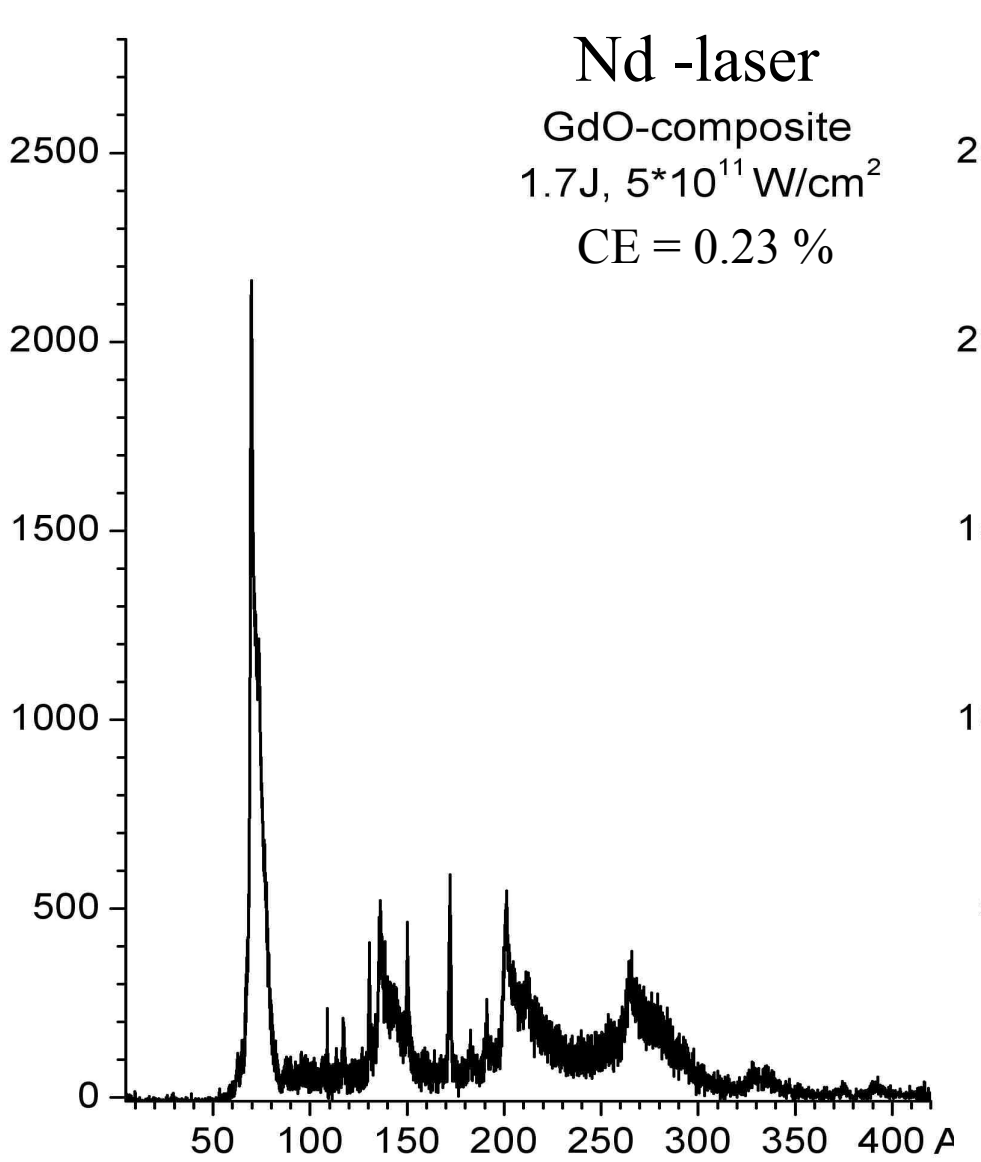
Geometry of the target

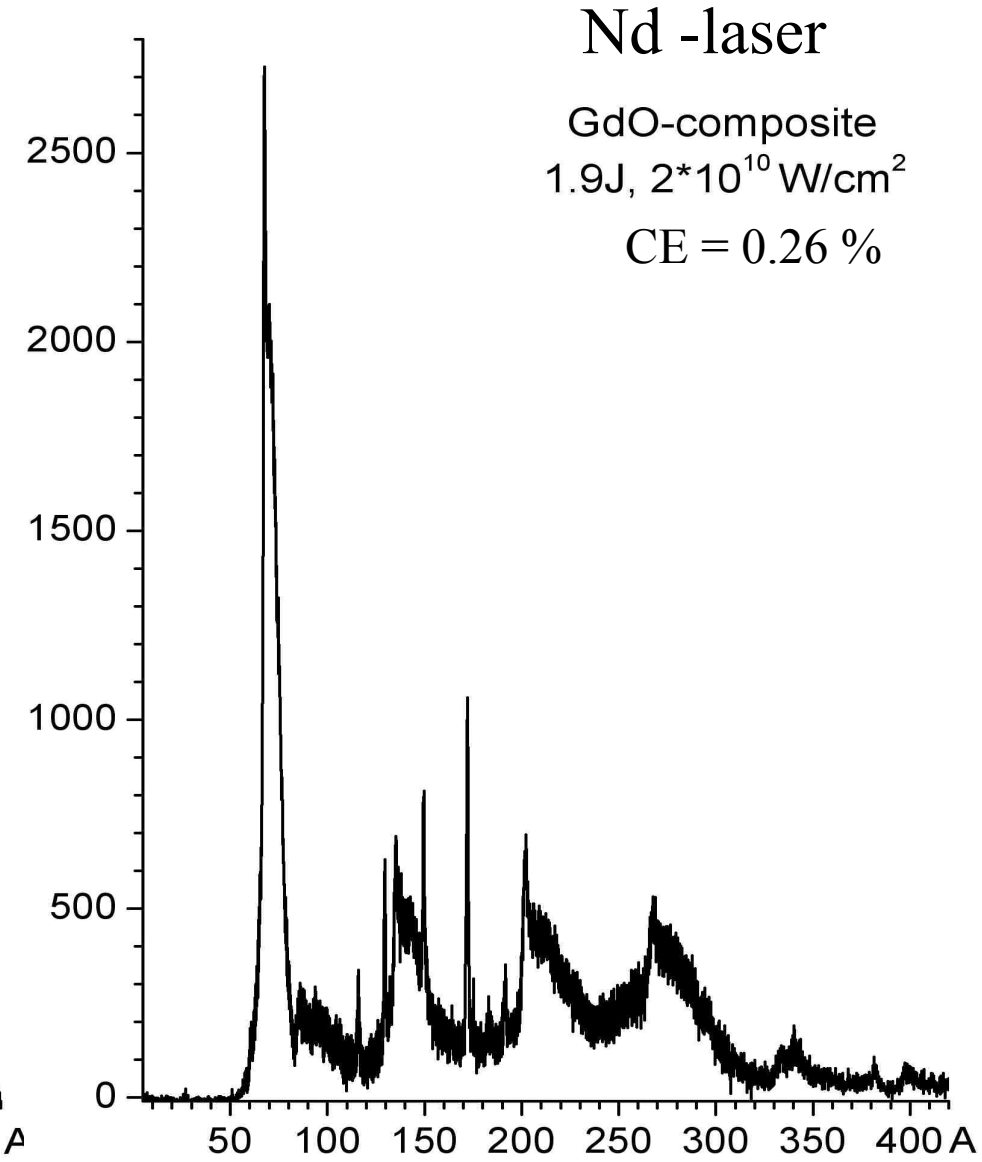
Nd laser + **Limited area target**



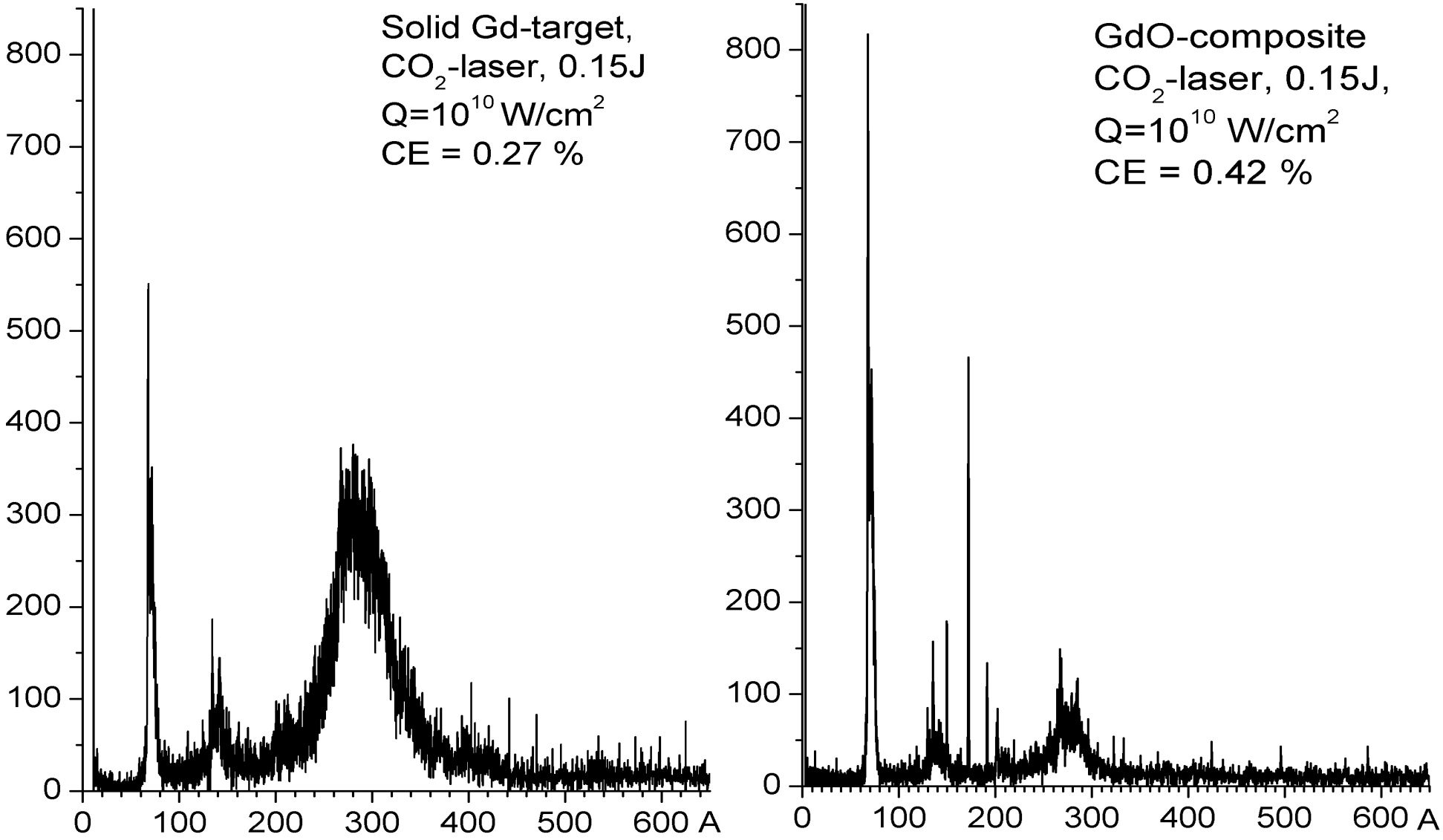


Chemical composition of the target

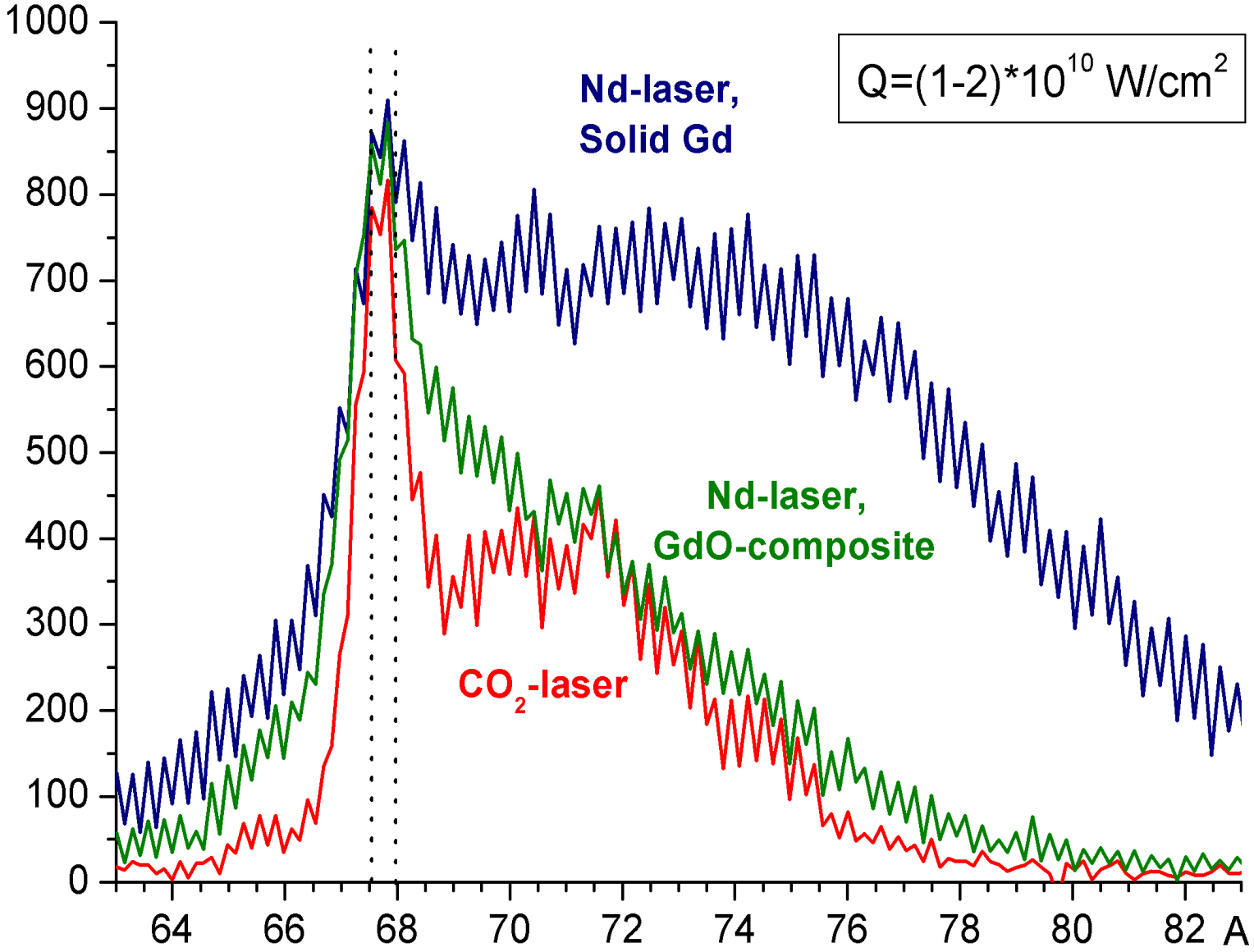




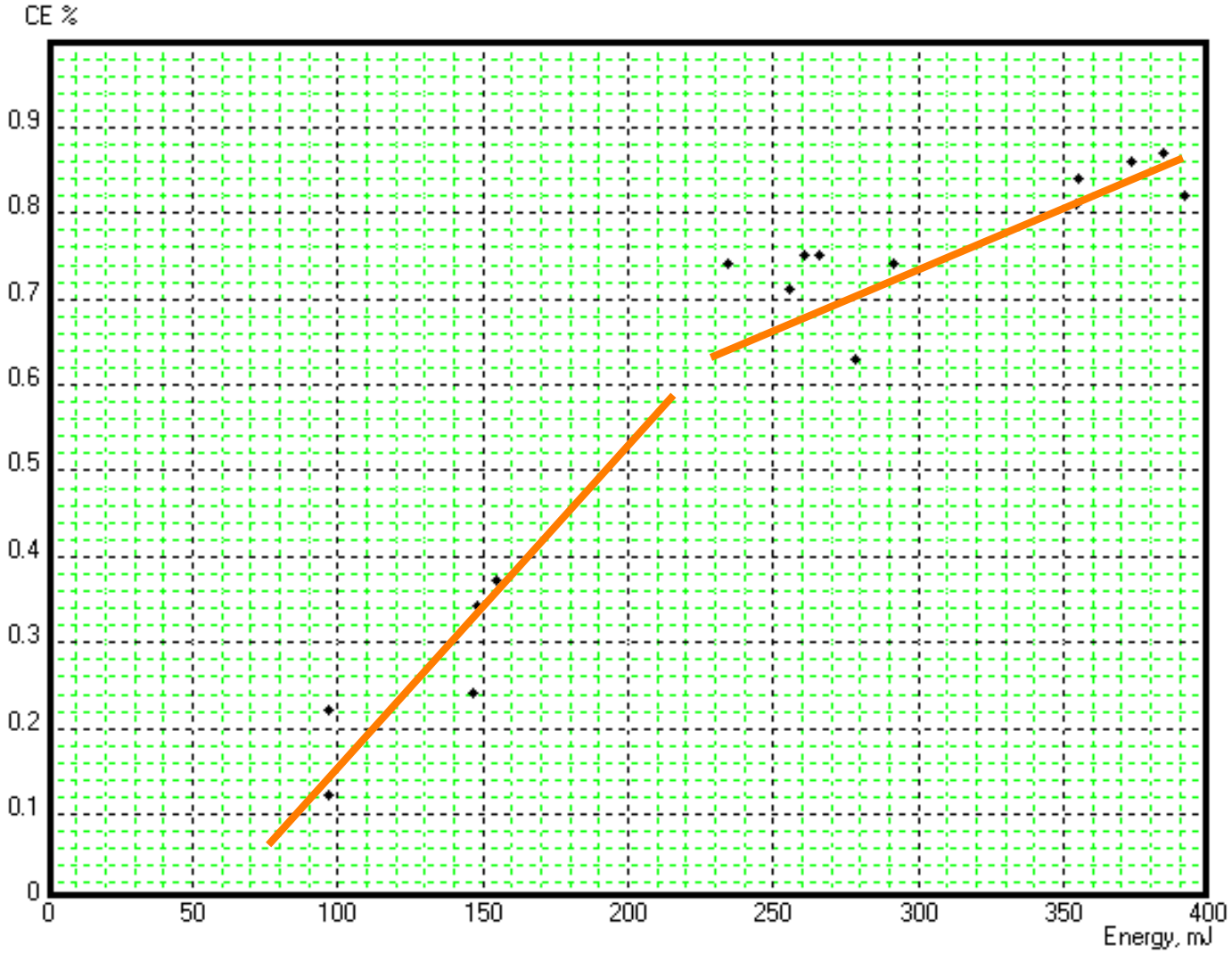
Wavelength of the laser



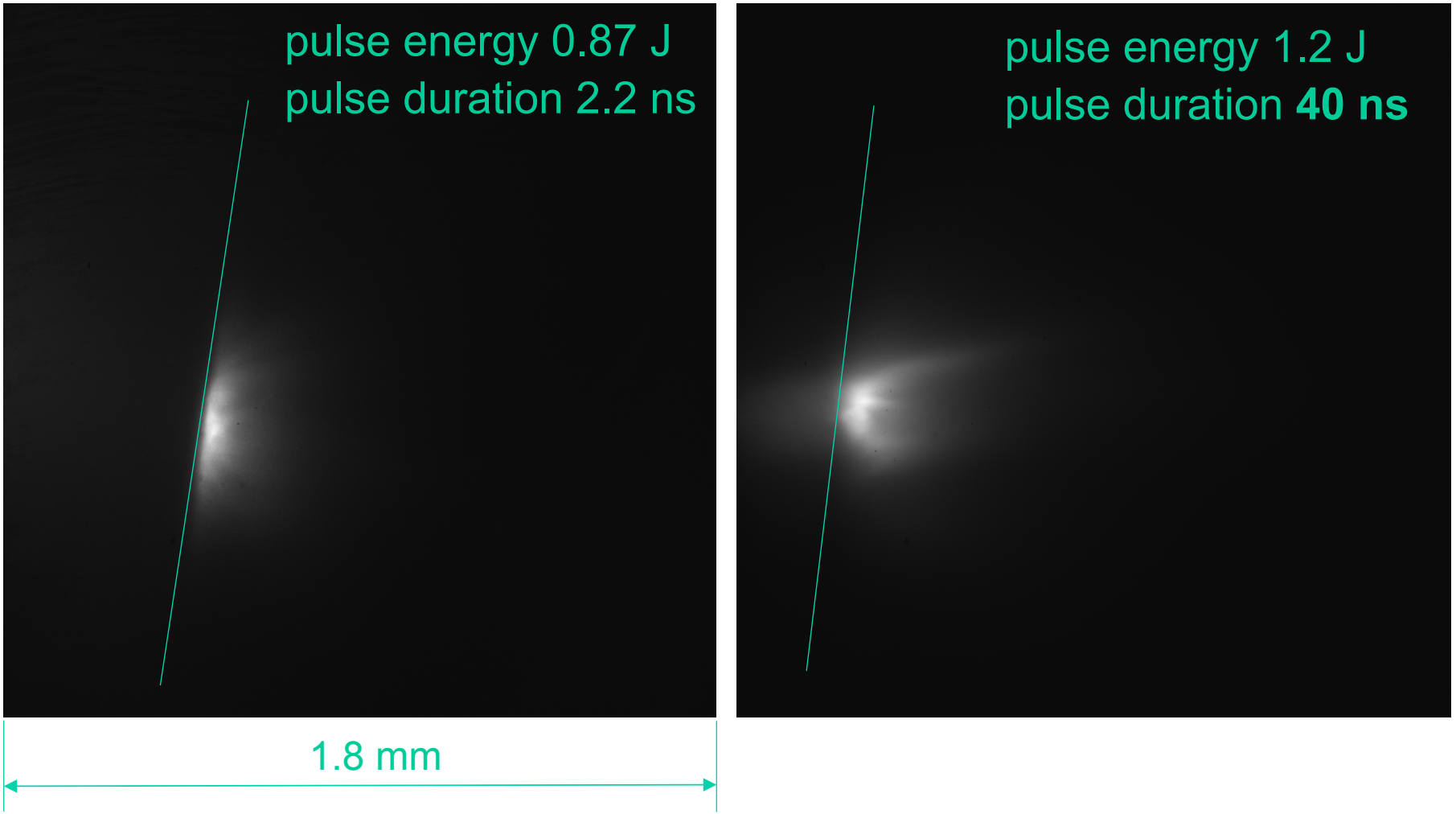
Characteristic profiles of the 4-4 transitions



CE with CO_2 laser on flat solid Gd target

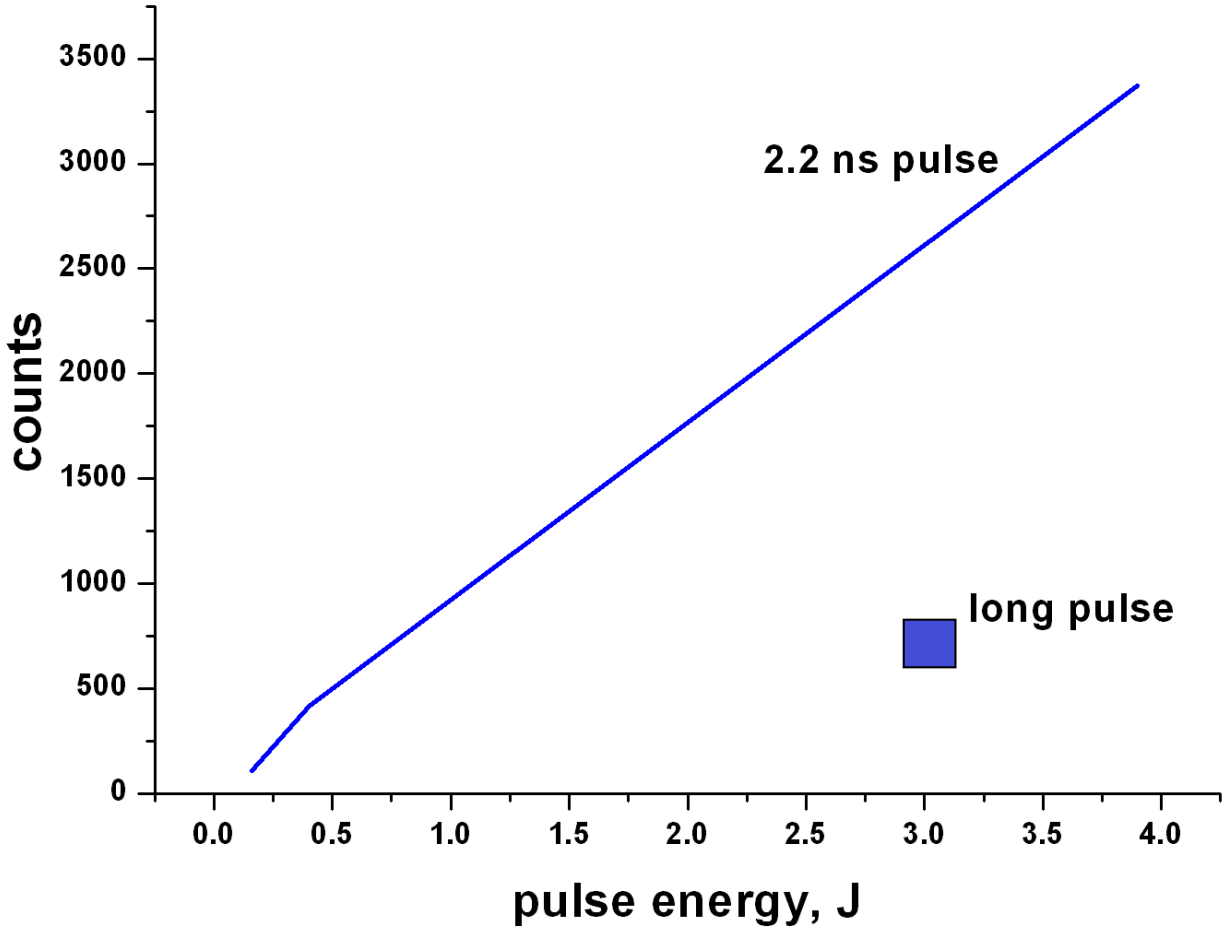


Pulse duration effects



Gd plasma images at different durations of Nd:YAG laser pulse

EUV intensity vs. laser energy and pulse duration



Summary and conclusions

- Optical transitions and energy level structure of Gd and Tb multi-charged ions were studied in details.
- Energy spectra and conversion efficiency coefficient (CE) in 0.5 % band around 6.775 nm for Gd plasmas produced with radiation of CO_2 (10.6μm) and Nd (1.06μm) lasers have been measured.
- In order to optimization coupling of laser excitation with emitting plasma different types of targets was tested.
- EUV yield dependencies on laser power density, spot size and laser pulse duration have been investigated.
- CE of about 1 % measured with a CO2 laser on solid bulk Gd targets, the highest CE about 2% was achieved on Gd foil perforated targets with a room for further increase.

Acknowledgements

The presented report is a result of work
of many people in ISAN-EUV team
and atomic spectroscopy department ISAN
All investigations was made in collaboration
and with support of ASML company

Thank You for Your Attention